

Strong 103 (does not have exact range).
 or d. 1 Na_2SiO_3



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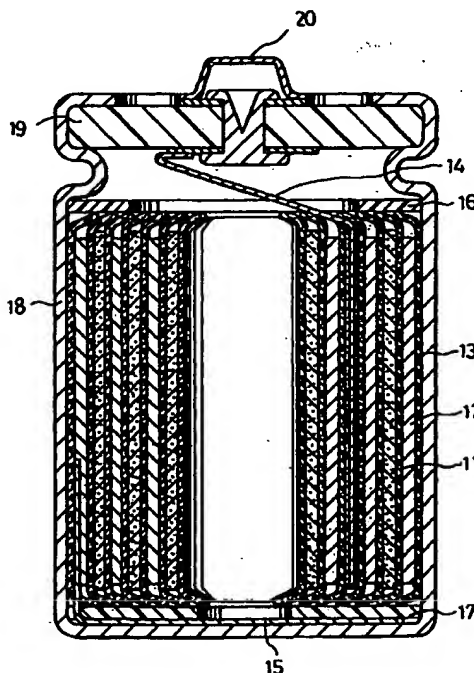
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(54) **Non-aqueous electrolyte secondary battery**

(57) Disclosed is a negative electrode active material offering a long life non-aqueous electrolyte secondary battery with high energy density that shows excellent cycle life characteristics. The negative electrode active material comprises a compound represented by the formula $\text{Li}_x\text{Z}_y\text{X}_z$, wherein Z represents at least two elements selected from the group consisting of metals and semi-metals at least one of which is selected from group D consisting of Na, K, Rb, Cs, Mg, Ca, Sr, Ba, Sc, Y, La, Ce, Ti, Zr, Hf, V, Nb, Ta, Cr, Mo, W, Mn, Fe, Co, Ni, Cu, Ag, Zn, Cd and Pd, and X represents at least one element selected from the group consisting of O, S, Se and Te and wherein $0 < x + y + z \leq 25$, $0 \leq x < 10$, $0 \leq y < 10$ and $0 < z \leq 8$.

FIG. 2



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Description

BACKGROUND OF THE INVENTION

5 The present invention relates to a non-aqueous electrolyte secondary battery, particularly an improvement of a negative electrode used therefor.

There have been various vigorous studies on a non-aqueous electrolyte secondary battery including lithium or a lithium compound as a negative electrode, because it is to be expected to offer a high voltage as well as a high energy density.

10 To date, oxides and chalcogens of transition metals like LiMn_2O_4 , LiCoO_2 , LiNiO_2 , V_2O_5 , Cr_2O_5 , MnO_2 , TiS_2 , MoS_2 and the like are known positive electrode active materials for non-aqueous electrolyte secondary batteries. Those compounds have a layered or tunneled crystal structure that allows free intercalation and deintercalation of lithium ions. On the other hand, there are many previous studies on metallic lithium as the negative electrode active material. However, metallic lithium has a drawback that when used as the negative electrode active material, a deposition of lithium dendrites occurs on the surface of lithium during charging, which reduces charge/discharge efficiency or causes internal short-circuiting due to contact between formed lithium dendrites and the positive electrode. As one measure for solving such drawback, the use of a lithium alloy such as lithium-aluminum alloy which not only suppresses the growth of lithium dendrites but also can absorb therein and desorb therefrom lithium as the negative electrode has been under investigation. However, the use of such lithium alloy has a drawback that repeated charge/discharge operation causes pulverization of the alloy as the electrode, which in turn deteriorates the cycle life characteristics of a battery.

20 Therefore, there are proposals to suppress pulverisation of the electrode by using a lithium-aluminum alloy including additional elements as electrode (e.g., Japanese Laid-Open Patent Publications Sho 62-119856 and Hei 4-109562). Under the circumstance, however, the improvement remains unsatisfactory. At present, lithium ion batteries have been put into practical use that include as the negative electrode a highly safe carbon material capable of reversibly absorbing and desorbing lithium and having exceptional cycle life characteristics although smaller in capacity than the above-mentioned negative electrode active materials. In an attempt to realize a higher capacity, various proposals have been made of an application of oxides to negative electrodes. For example, it is suggested in Japanese Laid-Open Patent Publications Hei 7-122274 and Hei 7-235293 that crystalline oxides such as SnO and SnO_2 may serve as negative electrode active materials with higher capacities than the conventional oxide WO_2 . There is another proposal in 30 Japanese Laid-Open Patent Publication Hei 7-288123 to use non-crystalline oxides such as SnSiO_3 or $\text{SnSi}_{1-x}\text{P}_x\text{O}_3$ for the negative electrode in order to improve the cycle life characteristics. But, the improvement is still unsatisfactory.

BRIEF SUMMARY OF THE INVENTION

35 The primary object of the present invention is to provide a negative electrode for non-aqueous electrolyte secondary batteries having excellent charge/discharge cycle life characteristics.

Another object of the present invention is to provide a negative electrode affording a high electric capacity and an exceptional cycle life by absorbing lithium upon charging without growing lithium dendrites.

40 The present invention provides a non-aqueous electrolyte secondary battery comprising a chargeable and dischargeable positive electrode, a non-aqueous electrolyte and a chargeable and dischargeable negative electrode, wherein the negative electrode comprises a compound represented by the formula (1)



45 wherein Z represents at least two elements selected from the group consisting of metals and semi-metals at least one of which is selected from group D consisting of Na, K, Rb, Cs, Mg, Ca, Sr, Ba, Sc, Y, La, Ce, Ti, Zr, Hf, V, Nb, Ta, Cr, Mo, W, Mn, Fe, Co, Ni, Cu, Ag, Zn, Cd and Pd, and X represents at least one element selected from the group consisting of O, S, Se and Te and wherein $0 < x + \gamma + \epsilon \leq 25$, $0 \leq x < 10$, $0 < \epsilon < 10$ and $0 < \gamma \leq 8$.

50 In a preferred mode of the present invention, Z comprises at least one element D selected from group D and at least one element A selected from group A consisting of Si, Ge, Sn, Pb, Bi, P, B, Ga, In, Al, As and Sb and is represented by the formula (2)



55 wherein $0 < \alpha$, $0 < \beta$ and $\alpha + \beta = \epsilon$.

In another preferred mode of the present invention, Z may comprise two elements D1 and D2 selected from group D and is represented by the formula (3)



wherein $0 < \delta$, $0 < \zeta$ and $\delta + \zeta = \varepsilon$.

In still another preferred mode of the present invention, Z may comprise three elements D1, D2 and D3 selected from group D and is represented by the formula (4)



wherein $0 < \delta$, $0 < \zeta$, $0 < \eta$ and $\delta + \zeta + \eta = \varepsilon$.

In a further preferred mode of the present invention, Z may comprise one element A selected from group A and two elements D1 and D2 selected from group D and is represented by the formula (5)



wherein $0 < \alpha < \beta$.

Furthermore, Z represented by the formula (2) is preferred to comprise two elements A1 and A2 selected from group A and one element D selected from group D and be represented by the formula (6)



wherein $0 < \alpha < \beta$.

In the above-mentioned compounds, the at least one element selected from group D is preferably be an alkaline earth metal element.

It is also preferable that the metal selected from group A is tin.

While the novel features of the invention are set forth particularly in the appended claims, the invention, both as to organization and content, will be better understood and appreciated, along with other objects and features thereof, from the following detailed description taken in conjunction with the drawings.

BRIEF DESCRIPTION OF SEVERAL VIEWS OF THE DRAWING

FIG. 1 is a brief longitudinal cross-sectional view of a test cell for evaluating the characteristics of an electrode of an active material in accordance with the present invention.

FIG. 2 is a longitudinal cross-sectional view of a cylindrical battery used for embodying the present invention

FIG. 3 is an X-ray diffraction pattern obtained from a negative electrode active material of a test cell upon cathode polarization at the 10th cycle.

DETAILED DESCRIPTION OF THE INVENTION

Upon being integrated in a battery, lithium is intercalated into the negative electrode active material in accordance with the present invention during charging in normal cases. In the formula $Li_\theta Z_\varepsilon X_\gamma$ representing the composition of a composite compound intercalated with lithium, the content of lithium represented by θ is preferably in a range of $1 \leq \theta < 10$. When $10 \leq \theta$ the compound can give only poor cycle life characteristics and thus not practical. On the other hand, when $\theta < 1$, the compound disadvantageously produces a small capacity. It is assumed that when such compound already intercalated with lithium is subjected to repeated intercalation and deintercalation of lithium by charge/discharge cycles, the compound loses its original composition partially. Therefore, it seems appropriate that the compound has a composition where the respective elements Li, Z and X are present in an atomic ratio of $\theta : \varepsilon : \gamma$.

According to the present invention, a highly reliable non-aqueous electrolyte secondary battery with a high energy density as well as an exceptional cycle life which is free from development of dendrite-induced short-circuiting.

In the following, the present invention will be described referring to specific examples, although the present invention is not limited thereto.

Example 1

In the present example, compounds or oxides represented by the formula (1) and whose X is oxygen were evaluated.

First, for evaluation of the electrode characteristics of those oxides as negative electrode active materials, test cells as shown in FIG. 1 were fabricated.

A mixture was prepared by mixing 3 g of a graphite powder as a conductive agent and 1 g of a polyethylene powder

as a binder with 6 g of each active material powder. Then, 0.1 g of the mixture was pressure-molded to a disc of 17.5 mm in diameter. An electrode 1 thus formed was placed in the center of a case 2 and disposed thereon with a separator 3 of a microporous polypropylene film. A non-aqueous electrolyte prepared by dissolving 1 mol/l lithium perchlorate (LiClO_4) in a mixed solvent of ethylene carbonate and dimethoxyethane in a volumetric ratio of 1:1 was injected over the separator 3. Next, the case 2 was combined with a sealing plate 6 having a polypropylene gasket 5 on the periphery thereof and attached with a metallic lithium disc 4 of 17.5 mm in diameter to the inner surface thereof, then was sealed to complete a test cell.

Each of the test cells thus produced was subjected to cathode polarization (corresponding to charging when the active material electrode is taken as the negative electrode) at a constant current of 2 mA until the electrode potential became 0 V vs. lithium counter electrode. Then, the test cell was subjected to anode polarization (corresponding to discharging) until the electrode potential dropped to 1.5 V vs. lithium counter electrode. Cathode and anode polarizations were repeated and the electrode characteristics were evaluated in all the test cells.

For comparison, conventional oxides and sulfides of metals listed in Table 1 were used.

The present example used those oxides listed in Table 2.

The discharge capacities per gram of the active material at the 1st cycle in the test cells are summarized in Tables 1 and 2, respectively.

All of the test cells including oxides of Example 1 in accordance with the present invention were found chargeable and dischargeable. Upon completion of cathode polarization at the 10th cycle, the test cells were disassembled and found to have no deposits of metallic lithium.

The above results indicated that the electrodes including the active materials in accordance with the present invention absorb therein lithium upon cathode polarization and desorb therefrom absorbed lithium upon anode polarization without growing dendrites of metallic lithium.

Next, for evaluation of the cycle life characteristics of the batteries applied with the negative electrodes of the active materials in accordance with the present invention, cylindrical batteries as shown in FIG. 2 were produced.

The batteries were produced as follows:

First, a positive electrode active material $\text{LiMn}_{1.8}\text{Co}_{0.2}\text{O}_4$ was synthesized by mixing Li_2CO_3 , Mn_2O_3 and CoCO_3 in a predetermined molar ratio, followed by heating at 900 °C. The resultant was further filtered through 100 mesh or less before used as the positive electrode active material of Example 1.

Then, to 100 g of the positive electrode active material, 10 g of a carbon powder as a conductive agent, 8 g (in solids) of an aqueous dispersion of polytetrafluoroethylene as a binder and pure water were added to form a paste. The paste was applied on a titanium core material, dried and rolled. In this way, a positive electrode plate was produced.

Separately, a negative electrode plate was prepared as follows: Each of various active materials, a graphite powder as a conductive agent and polytetrafluoroethylene as a binder were mixed in a weight ratio of 60:30:10 and the mixture was made into a paste using a petroleum solvent. The paste was applied on a copper core material, followed by drying at 100 °C to form a negative electrode plate. A porous polypropylene film was used as the separator.

Then, a positive electrode plate 11 having a spot-welded positive electrode lead 14 made of the same material as that of the core material was combined with a negative electrode plate 12 similarly having a spot-welded negative electrode lead 15 made of the same material as that of the core material together with a band-like separator 13 of a porous polypropylene film interposed therebetween and the combination was spirally rolled up to make an electrode group. The electrode group was placed in a battery case 18 after adhering polypropylene insulating plates 16 and 17 to the top and the bottom of the electrode group. A step was formed at the upper part of the battery case 18 and a non-aqueous electrolyte prepared by dissolving 1 mol/l lithium perchlorate in a mixed solvent of ethylene carbonate and dimethoxyethane in an equivolumetric ratio was injected into the battery case 18. Then, the case was sealed using a sealing plate 19 provided with a positive terminal 20 to form a battery.

Each of the batteries thus formed was subjected to a charge/discharge cycle test under conditions of a temperature of 30 °C, a charge/discharge current of 1 mA/cm² and a charge/discharge voltage in a range of 4.3 to 2.6 V.

Tables 1 and 2 summarize the discharge capacity maintenance ratios after 100 cycles in the batteries including negative electrodes of the oxides of the comparative example and Example 1, using their discharge capacities at the 2nd cycle as reference.

Table 1

Oxide or sulfide	Capacity (mAh/g)	Capacity maintenance rate (%)
WO_2	190	9
Fe_2O_3	185	10

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Table 1 (continued)

Oxide or sulfide	Capacity (mAh/g)	Capacity maintenance rate (%)
SnO	522	5
SnSiO ₃	453	20
PbO	453	2
SnS	498	6
PbS	436	3
SnSi _{0.8} P _{0.2} O _{3.1}	406	25

Table 2

	Oxides	Capacity (mAh/g)	Capacity maintenance rate (%)
5	Al_2MgO_4	360	90
10	MgSnO_3	550	85
	MgSiO_3	400	80
	MgPbO_3	600	90
15	MgCdO_2	350	85
	MgBi_2O_6	300	80
	MgIn_2O_4	460	85
	MgZnO_2	400	90
20	MgGa_2O_4	390	85
	Mg_2GeO_4	450	90
	Al_2CaO_4	370	90
25	CaSnO_3	570	90
	CaSiO_3	400	85
	CaPbO_3	600	90
	CaCdO_2	390	85
30	CaBi_2O_6	320	80
	CaIn_2O_4	520	80
	CaZnO_2	400	90
35	CaGa_2O_4	390	85
	Ca_2GeO_4	510	85
	Al_2SrO_4	380	85
40	SrSnO_3	630	95
	SrSiO_3	450	90
	SrPbO_3	600	85
	SrCdO_2	400	85
45	SrBi_2O_6	320	90
	SrIn_2O_4	500	90
	SrZnO_2	410	85
	SrGa_2O_4	410	90
50	Sr_2GeO_4	520	80

Table 2-continued

	Oxides	Capacity (mAh/g)	Capacity maintenance rate (%)
5			
	Al_2BaO_4	390	85
10	BaSnO_3	400	95
	BaSiO_3	400	85
	BaPbO_3	580	90
15	BaCdO_2	390	80
	BaBi_2O_6	410	80
	BaIn_2O_4	530	85
	BaZnO_2	400	85
20	BaGa_2O_4	400	90
	Ba_2GeO_4	500	90
	$\text{Ba}_{0.5}\text{Sr}_{0.5}\text{SnO}_3$	600	95
25	$\text{Ba}_{0.7}\text{Sr}_{0.3}\text{SnO}_3$	620	95
	$\text{Ba}_{0.9}\text{Sr}_{0.1}\text{SnO}_3$	630	95
	$\text{Ba}_{0.5}\text{Ca}_{0.5}\text{SnO}_3$	600	90
	$\text{Ba}_{0.5}\text{Mg}_{0.5}\text{SnO}_3$	580	90
30	$\text{Ba}_{0.5}\text{Sr}_{0.5}\text{SiO}_3$	500	90
	$\text{Ba}_{0.5}\text{Sr}_{0.5}\text{PbO}_3$	620	90
	$\text{Al}_2\text{Na}_2\text{O}_4$	420	90
35	Na_2SnO_3	400	90
	Na_2SiO_3	400	85
	Na_2PbO_3	600	80
40	Na_2CdO_2	400	85
	$\text{Na}_2\text{Bi}_2\text{O}_6$	380	80
	$\text{Na}_2\text{In}_2\text{O}_4$	550	85
	Na_2ZnO_2	400	85
45	$\text{Na}_2\text{Ga}_2\text{O}_4$	400	90
	Na_4GeO_4	500	85
	$\text{Al}_2\text{K}_2\text{O}_4$	430	90
50	K_2SnO_3	450	90
	K_2SiO_3	420	90

46 + 28 + 48

Table 2-continued

5	Oxides	Capacity (mAh/g)	Capacity maintenance rate (%)
10	K_2PbO_3	580	85
	K_2CdO_2	400	85
	$K_2Bi_2O_6$	390	80
	$K_2In_2O_4$	570	85
15	K_2ZnO_2	400	85
	$K_2Ga_2O_4$	400	90
	Rb_4GeO_4	510	85
	Rb_2SnO_3	450	90
20	Rb_2SiO_3	420	90
	Rb_2PbO_3	580	85
	Rb_2CdO_2	400	85
25	$Rb_2Bi_2O_6$	390	80
	$Rb_2In_2O_4$	570	85
	Rb_2ZnO_2	400	85
	$Rb_2Ga_2O_4$	400	90
30	Rb_4GeO_4	510	85
	$SrAl_2SnO_5$	550	90
	$SrAl_2SiO_5$	400	85
35	$SrAl_2PbO_5$	600	80
	$SrAl_2CdO_4$	350	90
	$SrAlBiO_4$	300	85
	$SrAlInO_3$	460	80
40	$SrAl_2ZnO_4$	400	85
	$SrAlGaO_3$	390	90
	$SrAl_2GeO_4$	450	85
45	$SrSnAl_2O_5$	360	90
	$SrSnSiO_4$	400	85
	$SrSnPbO_4$	600	80
	$SrSnCdO_3$	350	90
50	$SrSnBi_2O_7$	300	85

55

Table 2-continued

5	Oxides	Capacity (mAh/g)	Capacity maintenance rate(%)
10	$\text{SrSnIn}_2\text{O}_5$	460	80
	SrSnZnO_3	400	85
	$\text{SrSnGa}_2\text{O}_5$	390	90
	$\text{SrSn}_2\text{GeO}_4$	450	85
15	$\text{BaSiAl}_2\text{O}_5$	360	90
	BaSiSnO_4	550	85
	BaSiPbO_4	600	80
	BaSiCdO_3	350	90
20	$\text{BaSiBi}_2\text{O}_7$	300	85
	$\text{BaSiIn}_2\text{O}_5$	460	80
	BaSiZnO_3	400	85
25	$\text{BaSiGa}_2\text{O}_5$	390	90
	$\text{BaSi}_2\text{GeO}_4$	450	85
	$\text{BaPbAl}_2\text{O}_5$	360	90
	BaPbSnO_4	550	85
30	BaPbSiO_4	400	80
	BaPbCdO_3	350	90
	$\text{BaPbBi}_2\text{O}_7$	300	85
35	$\text{BaPbIn}_2\text{O}_5$	460	80
	BaPbZnO_3	400	85
	$\text{BaPbGa}_2\text{O}_5$	390	90
	$\text{BaPb}_2\text{GeO}_4$	450	85
40	CdAl_2O_4	360	90
	CdSnO_3	550	85
	CdSiO_3	400	80
45	CdPbO_3	600	90
	CdBiO_4	300	85
	CdIn_2O_4	460	80
	CdZnO_2	400	85
50	CdGa_2O_4	390	90

Table 2-continued

5	Oxides	Capacity (mAh/g)	Capacity maintenance rate (%)
	Cd_2GeO_4	4 5 0	8 5
10	BaBiAlO_4	3 6 0	9 0
	$\text{BaBi}_2\text{SnO}_7$	5 5 0	8 5
	$\text{BaBi}_2\text{SiO}_7$	4 0 0	8 0
15	$\text{BaBi}_2\text{PbO}_7$	6 0 0	9 0
	$\text{BaBi}_2\text{CdO}_6$	3 5 0	8 5
	BaBiInO_4	4 6 0	8 0
	$\text{BaBi}_2\text{ZnO}_6$	4 0 0	8 5
20	BaBiGaO_4	3 9 0	9 0
	$\text{BaBi}_2\text{GeO}_4$	4 5 0	8 5
	SrInAlO_3	3 6 0	9 0
25	$\text{SrIn}_2\text{SnO}_5$	5 5 0	8 5
	$\text{SrIn}_2\text{SiO}_5$	4 0 0	8 0
	$\text{SrIn}_2\text{PbO}_5$	6 0 0	9 0
	$\text{SrIn}_2\text{CdO}_4$	3 5 0	8 5
30	SrInBiO_4	3 0 0	8 0
	$\text{SrIn}_2\text{ZnO}_4$	4 0 0	8 5
	SrInGaO_3	3 9 0	9 0
	$\text{SrIn}_2\text{GeO}_4$	4 5 0	8 5
35	ZnAl_2O_4	3 6 0	9 0
	ZnSnO_4	5 5 0	8 5
	ZnSiO_4	4 0 0	8 0
40	ZnPbO_3	6 0 0	9 0
	ZnCdO_2	3 5 0	8 5
	ZnBi_2O_6	3 0 0	8 0
	ZnIn_2O_4	4 6 0	8 5
45	ZnGa_2O_4	3 9 0	9 0
	Zn_2GeO_4	4 5 0	8 5
	MgGaAlO_3	3 6 0	9 0
50	$\text{MgGa}_2\text{SnO}_5$	5 5 0	8 5

Table 2-continued

5	Oxides	Capacity (mAh/g)	Capacity maintenance rate (%)
10	$\text{MgGa}_2\text{SiO}_7$	400	80
	$\text{MgGa}_2\text{PbO}_5$	600	90
	$\text{MgGa}_2\text{CdO}_4$	350	85
15	MgGaBiO_4	300	80
	MgGaInO_3	460	85
	$\text{MgGa}_2\text{ZnO}_4$	400	90
	$\text{MgGa}_2\text{GeO}_4$	450	85
20	$\text{MgGeAl}_2\text{O}_5$	360	90
	MgGeSnO_4	550	85
	MgGeSiO_4	400	80
25	MgGePbO_4	600	90
	MgGeCdO_3	350	85
	$\text{MgGeBi}_2\text{O}_7$	300	80
30	$\text{MgGeIn}_2\text{O}_5$	460	85
	MgGeZnO_3	400	90
	$\text{MgGeGa}_2\text{O}_5$	390	85

35

As is evident from the tables, the batteries using the negative electrodes of the oxide active materials in accordance with the present invention are improved drastically in the cycle life characteristics as compared with those using the negative electrodes of the conventional oxides.

Next, the factor contributing to the improved cycle life characteristics of the above-mentioned active materials of the present invention was analyzed. FIG. 3 shows an X-ray diffraction pattern obtained from the test cell using MgSnO_3 as the negative electrode active material upon completion of cathode polarization (charged state of the negative electrode active material) at the 10th cycle. The figure also lists the result in the test cell using the comparative example active material SnO_2 . Noting the peak around $2\theta=38^\circ$, a sharp peak clearly indicating the presence of an Li-Sn alloy was observed in the comparative example oxide. On the other hand, a very broad peak with a low peak intensity was observed in the oxide of Example 1.

The above findings suggested that the charge/discharge reaction in the comparative example oxide SnO_2 develops basically by the alloying reaction between Sn and Li. In the oxide MgSnO_3 of Example 1, although it was speculated that this oxide also experiences the same reaction, it shows a broad peak with very low peak intensity on the X-ray diffraction pattern as compared with the comparative example. This suggests very low crystallinity of the Li-Sn alloy synthesized during charge of MgSnO_3 as compared with the comparative example oxide SnO_2 . Although the details remain to be clarified more, the low crystallinity was considered to result from the prevention by the presence of the group D element Mg of a reduction of the reactive surface area or inactivation due to an aggregation of the group A element Sn. This seems to have led to improved cycle life characteristics.

Although only MgSnO_3 was exemplified above, the same observations were obtained from the rest of the active materials.

Example 2

In the present example, test cells were produced in the same manner as in Example 1 for evaluation of the electrode characteristics of the negative electrode active materials of various sulfides listed in Table 3. The evaluation was performed under the same conditions as applied in Example 1. The results are summarized in Table 3.

All the test cells of Example 2 were found chargeable and dischargeable. Upon completion of cathode polarization at the 10th cycle, the test cells were disassembled and found to have no deposits of metallic lithium.

From this, it was indicated that the electrodes including the active materials in accordance with the present invention absorb therein lithium upon cathode polarization and desorb therefrom absorbed lithium upon anode polarization without growing dendrites of metallic lithium.

Next, for evaluation of the cycle life characteristics of the batteries applied with the negative electrodes of the various sulfides in accordance with the present invention, cylindrical batteries as used in Example 1 were produced and evaluated under the same conditions as in Example 1. The results are summarized in Table 3.

Table 3

	Sulfides	Capacity (mAh/g)	Capacity maintenance rate (%)
5			
	Al_2MgS_4	360	90
10	MgSnS_3	550	85
	MgSiS_3	400	80
	MgPbS_3	600	90
15	MgCdS_2	350	85
	MgBi_2S_6	300	80
	MgIn_2S_4	460	85
	MgZnS_2	400	90
20	MgGa_2S_4	390	85
	Mg_2GeS_4	450	90
	Al_2CaS_4	370	90
25	CaSnS_3	580	90
	CaSiS_3	400	85
	CaPbS_3	620	90
	CaCdS_2	380	85
30	CaBi_2S_6	320	80
	CaIn_2S_4	500	80
	CaZnS_2	400	90
35	CaGa_2S_4	370	85
	Ca_2GeS_4	500	85
	Al_2SrS_4	380	85
40	SrSnS_3	600	95
	SrSiS_3	450	90
	SrPbS_3	620	85
	SrCdS_2	400	85
45	SrBi_2S_6	330	90
	SrIn_2S_4	530	90
	SrZnS_2	400	85
50	SrGa_2S_4	400	90
	Sr_2GeS_4	510	80

55

Table 3-continued

	Sulfides	Capacity (mAh/g)	Capacity maintenance rate (%)
5			
	Al_2BaS_4	370	85
10	BaSnS_3	410	95
	BaSiS_3	440	85
	BaPbS_3	450	90
15	BaCdS_2	390	80
	BaBi_2S_6	400	80
	BaIn_2S_4	490	85
	BaZnS_2	400	85
20	BaGa_2S_4	400	90
	Ba_2GeS_4	500	90
	$\text{Ba}_{0.5}\text{Sr}_{0.6}\text{SnS}_3$	620	95
25	$\text{Ba}_{0.7}\text{Sr}_{0.3}\text{SnS}_3$	630	95
	$\text{Ba}_{0.9}\text{Sr}_{0.1}\text{SnS}_3$	630	95
	$\text{Ba}_{0.5}\text{Ca}_{0.5}\text{SnS}_3$	580	90
	$\text{Ba}_{0.5}\text{Mg}_{0.5}\text{SnS}_3$	570	90
30	$\text{Ba}_{0.5}\text{Sr}_{0.5}\text{SiS}_3$	500	90
	$\text{Ba}_{0.5}\text{Sr}_{0.5}\text{PbS}_3$	620	90
	$\text{Al}_2\text{Na}_2\text{S}_4$	390	90
35	Na_2SnS_3	470	90
	Na_2SiS_3	420	85
	Na_2PbS_3	580	80
	Na_2CdS_2	400	85
40	$\text{Na}_2\text{Bi}_2\text{S}_6$	380	80
	$\text{Na}_2\text{In}_2\text{S}_4$	520	85
	Na_2ZnS_2	370	85
45	$\text{Na}_2\text{Ga}_2\text{S}_4$	400	90
	Na_4GeS_4	500	85
	$\text{Al}_2\text{K}_2\text{S}_4$	400	90
	K_2SnS_3	450	90
50	K_2SiS_3	420	90

Table 3-continued

	Sulfides	Capacity (mAh/g)	Capacity maintenance rate (%)
5			
	K_2PbS_3	580	85
10	K_2CdS_2	400	85
	$K_2Bi_2S_6$	390	80
	$K_2In_2S_4$	570	85
15	K_2ZnS_2	400	85
	$K_2Ga_2S_4$	420	90
	K_4GeS_4	510	85
	$Na_2Al_2SnS_5$	550	90
20	$Na_2Al_2SiS_5$	400	85
	$Na_2Al_2PbS_5$	600	80
	$Na_2Al_2CdS_4$	350	90
25	Na_2AlBiS_4	300	85
	Na_2AlInS_3	460	80
	$Na_2Al_2ZnS_4$	400	85
	Na_2AlGaS_3	390	90
30	$Na_2Al_2GeS_4$	450	85
	$SrSnAl_3S_5$	360	90
	$SrSnSiS_4$	400	85
35	$SrSnPbS_4$	600	80
	$SrSnCdS_3$	350	90
	$SrSnBi_2S_7$	300	85
	$SrSnIn_2S_5$	460	80
40	$SrSnZnS_3$	400	85
	$SrSnGa_2S_5$	390	90
	$SrSn_2GeS_4$	450	85
45	$BaSiAl_2S_5$	360	90
	$BaSiSnS_4$	550	85
	$BaSiPbS_4$	600	80
50	$BaSiCdS_3$	350	90
	$BaSiBi_2S_7$	300	85

Table 3-continued

5	Sulfides	Capacity (mAh/g)	Capacity maintenance rate (%)
	BaSiIn ₂ S ₅	460	80
10	BaSiZnS ₃	400	85
	BaSiGa ₂ S ₅	390	90
	BaSi ₂ GeS ₄	450	85
15	CaPbAl ₂ S ₅	360	90
	CaPbSnS ₄	550	85
	CaPbSiS ₄	400	80
	CaPbCdS ₃	350	90
20	CaPbBi ₂ S ₇	300	85
	CaPbIn ₂ S ₅	460	80
	CaPbZnS ₃	400	85
25	CaPbGa ₂ S ₅	390	90
	CaPb ₂ GeS ₄	450	85
	CaCdAl ₂ S ₄	360	90
	CaCdSnS ₃	550	85
30	CaCdSiS ₃	400	80
	CaCdPbS ₃	600	90
	CaCdBiS ₄	300	85
35	CaCdIn ₂ S ₄	460	80
	CaCdZnS ₂	400	85
	CaCdGa ₂ S ₅	390	90
	CaCd ₂ GeS ₅	450	85
40	MgBiAlS ₅	360	90
	MgBi ₂ SnS ₈	550	85
	MgBi ₂ SiS ₈	400	80
45	MgBi ₂ PbS ₈	600	90
	MgBi ₂ CdS ₇	350	85
	MgBiInS ₅	460	80
50	MgBi ₂ ZnS ₇	400	85
	MgBiGaS ₅	390	90

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Table 3-continued

	Sulfides	Capacity (mAh/g)	Capacity maintenance rate (%)
5	$\text{MgBi}_2\text{GeS}_5$	450	85
10	K_2InAlS_4	360	90
	$\text{K}_2\text{In}_2\text{SnS}_6$	550	85
	$\text{K}_2\text{In}_2\text{SiS}_6$	400	80
15	$\text{K}_2\text{In}_2\text{PbS}_6$	600	90
	$\text{K}_2\text{In}_2\text{CdS}_5$	350	85
	K_2InBiS_5	300	80
	$\text{K}_2\text{In}_2\text{ZnS}_5$	400	85
20	K_2InGaS_4	390	90
	$\text{K}_2\text{In}_2\text{GeS}_5$	450	85
	ZnAl_2S_4	360	90
25	ZnSnS_4	550	85
	ZnSiSn_4	400	80
	ZnPbS_3	600	90
	ZnCdS_2	350	85
30	ZnBi_2S_6	300	80
	ZnIn_2S_4	460	85
	ZnGa_2S_4	390	90
35	Zn_2GeS_4	450	85
	SrGaAlS_4	360	90
	$\text{SrGa}_2\text{SnS}_6$	550	85
	$\text{SrGa}_2\text{SiS}_8$	400	80
40	$\text{SrGa}_2\text{PbS}_6$	600	90
	$\text{SrGa}_2\text{CdS}_5$	350	85
	SrGaBiS_5	300	80
45	SrGaInS_4	460	85
	$\text{SrGa}_2\text{ZnS}_5$	400	90
	$\text{SrGa}_2\text{GeS}_5$	450	85
	$\text{BaGeAl}_2\text{S}_6$	360	90
50	BaGeSnS_5	550	85

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Table 3-continued

Sulfides	Capacity (mAh/g)	Capacity maintenance rate (%)
B a G e S i S ₅	4 0 0	8 0
B a G e P b S ₅	6 0 0	9 0
B a G e C d S ₄	3 5 0	8 5
B a G e B i ₂ S ₈	3 0 0	8 0
B a G e I n ₂ S ₆	4 6 0	8 5
B a G e Z n S ₄	4 0 0	9 0
B a G e G a ₂ S ₆	3 9 0	8 5

As is clear from Table 3, the batteries using the various sulfides in accordance with the present invention as the negative electrode active materials are improved in the cycle life characteristics as compared with those using the conventional negative electrode active materials.

Example 3

In Example 3, test cells were produced in the same manner as in Example 1 for evaluation of the electrode characteristics of the negative electrode active materials of various selenates listed in Table 4. The evaluation was performed under the same conditions as applied in Example 1. All the test cells of Example 3 were found chargeable and dischargeable. Upon completion of cathode polarization at the 10th cycle, the test cells were disassembled and found to have no deposits of metallic lithium.

From this, it was indicated that the electrodes including the active materials in accordance with the present invention absorb therein lithium upon cathode polarization and desorb therefrom absorbed lithium upon anode polarization without growing dendrites of metallic lithium.

Next, for evaluation of the cycle life characteristics of the batteries applied with the negative electrode active materials of various selenates in accordance with the present invention, cylindrical batteries as used in Example 1 were produced and evaluated under the same conditions as in Example 1. The results are summarized in Table 4.

Table 4

	Selenides	Capacity (mAh/g)	Capacity maintenance rate (%)
5			
	Al_2MgSe_4	360	90
10	MgSnSe_3	550	85
	MgSiSe_3	400	80
	MgPbSe_3	600	90
15	MgCdSe_2	350	85
	MgBi_2Se_6	300	80
	MgIn_2Se_4	460	85
	MgZnSe_2	400	90
20	MgGa_2Se_4	390	85
	Mg_2GeSe_4	450	90
	Al_2CaSe_4	370	90
25	CaSnSe_3	570	90
	CaSiSe_3	400	85
	CaPbSe_3	600	90
	CaCdSe_2	390	85
30	CaBi_2Se_6	320	80
	CaIn_2Se_4	520	80
	CaZnSe_2	400	90
35	CaGa_2Se_4	390	85
	Ca_2GeSe_4	510	85
	Al_2SrSe_4	380	85
40	SrSnSe_3	630	95
	SrSiSe_3	450	90
	SrPbSe_3	600	85
	SrCdSe_2	400	85
45	SrBi_2Se_6	320	90
	SrIn_2Se_4	500	90
	SrZnSe_2	410	85
50	SrGa_2Se_4	410	90
	Sr_2GeSe_4	520	80

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Table 4-continued

	Selenides	Capacity (mAh/g)	Capacity maintenance rate (%)
5			
	Al_2BaSe_4	390	85
10	BaSnSe_3	400	95
	BaSiSe_3	400	85
	BaPbSe_3	580	90
15	BaCdSe_2	390	80
	BaBi_2Se_6	410	80
	BaIn_2Se_4	530	85
	BaZnSe_2	400	85
20	BaGa_2Se_4	400	90
	Ba_2GeSe_4	500	90
	$\text{Ba}_{0.5}\text{Sr}_{0.5}\text{SnSe}_3$	600	95
25	$\text{Ba}_{0.7}\text{Sr}_{0.3}\text{SnSe}_3$	620	95
	$\text{Ba}_{0.9}\text{Sr}_{0.1}\text{SnSe}_3$	630	95
	$\text{Ba}_{0.5}\text{Ca}_{0.5}\text{SnSe}_3$	600	90
	$\text{Ba}_{0.5}\text{Mg}_{0.5}\text{SnSe}_3$	580	90
30	$\text{Ba}_{0.5}\text{Sr}_{0.5}\text{SiSe}_3$	500	90
	$\text{Ba}_{0.5}\text{Sr}_{0.5}\text{PbSe}_3$	620	90
	$\text{Al}_2\text{Na}_2\text{Se}_4$	420	90
35	Na_2SnSe_3	400	90
	Na_2SiSe_3	400	85
	Na_2PbSe_3	600	80
	Na_2CdSe_2	400	85
40	$\text{Na}_2\text{Bi}_2\text{Se}_6$	380	80
	$\text{Na}_2\text{In}_2\text{Se}_4$	550	85
	Na_2ZnSe_2	400	85
45	$\text{Na}_2\text{Ga}_2\text{Se}_4$	400	90
	Na_4GeSe_4	500	85
	$\text{Al}_2\text{K}_2\text{Se}_4$	430	90
50	K_2SnSe_3	450	90
	K_2SiSe_3	420	90

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Table 4-continued

	Selenides	Capacity (mAh/g)	Capacity maintenance rate (%)
5			
	K_2PbSe_3	580	85
10	K_2CdSe_2	400	85
	$K_2Bi_2Se_6$	390	80
	$K_2In_2Se_4$	570	85
15	K_2ZnSe_2	400	85
	$K_2Ga_2Se_4$	400	90
	K_4GeSe_4	510	85
	$SrAl_2SiSe_6$	400	85
20	$SrAl_2PbSe_6$	600	80
	$SrAl_2CdSe_5$	350	90
	$SrAlBiSe_5$	300	85
25	$SrAlInSe_4$	460	80
	$SrAl_2ZnSe_5$	400	85
	$SrAlGaSe_4$	390	90
	$SrAl_2GeSe_5$	450	85
30	$BaSnAl_2Se_6$	360	90
	$BaSnSiSe_5$	400	85
	$BaSnPbSe_5$	600	80
35	$BaSnCdSe_4$	350	90
	$BaSnBi_2Se_8$	300	85
	$BaSnIn_2Se_6$	460	80
	$BaSnZnSe_4$	400	85
40	$BaSnGa_2Se_6$	390	90
	$BaSn_2GeSe_5$	450	85
	$K_2SiAl_2Se_6$	360	90
45	$K_2SiSnSe_5$	550	85
	$K_2SiPbSe_5$	600	80
	$K_2SiCdSe_4$	350	90
	$K_2SiBi_2Se_8$	300	85
50	$K_2SiIn_2Se_6$	460	80

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Table 4-continued

5	Selenides	Capacity (mAh/g)	Capacity maintenance rate (%)
	$K_2SiZnSe_4$	400	85
10	$K_2SiGa_2Se_6$	390	90
	$K_2Si_2GeSe_5$	450	85
	$MgPbAl_2Se_6$	360	90
15	$MgPbSnSe_5$	550	85
	$MgPbSiSe_5$	400	80
	$MgPbCdSe_4$	350	90
	$MgPbBi_2Se_8$	300	85
20	$MgPbIn_2Se_6$	460	80
	$MgPbZnSe_4$	400	85
	$MgPbGa_2Se_6$	390	90
25	$MgPb_2GeSe_5$	450	85
	$CdAl_2Se_4$	360	90
	$CdSnSe_3$	550	85
	$CdSiSe_3$	400	80
30	$CdPbSe_3$	600	90
	$CdBiSe_4$	300	85
	$CdIn_2Se_4$	460	80
35	$CdZnSe_2$	400	85
	$CdGa_2Se_4$	390	90
	Cd_2GeSe_4	450	85
	$CaBiAlSe_5$	360	90
40	$CaBi_2SnSe_8$	550	85
	$CaBi_2SiSe_8$	400	80
	$CaBi_2PbSe_8$	600	90
45	$CaBi_2CdSe_7$	350	85
	$CaBiInSe_5$	460	80
	$CaBi_2ZnSe_7$	400	85
50	$CaBiGaSe_5$	390	90
	$CaBi_2GeSe_5$	450	85

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Table 4-continued

	Selenides	Capacity (mAh/g)	Capacity maintenance rate (%)
5			
	SrInAlSe_4	360	90
10	$\text{SrIn}_2\text{SnSe}_6$	550	85
	$\text{SrIn}_2\text{SiSe}_6$	400	80
	$\text{SrIn}_2\text{PbSe}_6$	600	90
15	$\text{SrIn}_2\text{CdSe}_5$	350	85
	SrInBiSe_5	300	80
	$\text{SrIn}_2\text{ZnSe}_5$	400	85
	SrInGaSe_4	390	90
20	$\text{SrIn}_2\text{GeSe}_5$	450	85
	ZnAl_2Se_4	360	90
	ZnSnSe_4	550	85
25	ZnSiSe_4	400	80
	ZnPbSe_3	600	90
	ZnCdSe_2	350	85
	ZnBi_2Se_6	300	80
30	ZnIn_2Se_4	460	85
	ZnGa_2Se_4	390	90
	Zn_2GeSe_4	450	85
35	MgGaAlSe_4	360	90
	$\text{MgGa}_2\text{SnSe}_6$	550	85
	$\text{MgGa}_2\text{SiSe}_8$	400	80
40	$\text{MgGa}_2\text{PbSe}_6$	600	90
	$\text{MgGa}_2\text{CdSe}_5$	350	85
	MgGaBiSe_5	300	80
	MgGaInSe_4	460	85
45	$\text{MgGa}_2\text{ZnSe}_5$	400	90
	$\text{MgGa}_2\text{GeSe}_5$	450	85
	$\text{SrGeAl}_2\text{Se}_6$	360	90
50	SrGeSnSe_5	550	85

Table 4-continued

Selenides	Capacity (mAh/g)	Capacity maintenance rate (%)
SrGeSiSe ₅	400	80
SrGePbSe ₅	600	90
SrGeCdSe ₄	350	85
SrGeBi ₂ Se ₈	300	80
SrGeIn ₂ Se ₆	460	85
SrGeZnSe ₄	400	90
SrGeGa ₂ Se ₆	390	85

As is evident from Table 4, the batteries using the various selenates in accordance with the present invention as the negative electrode active materials are improved in the cycle life characteristics as compared with those using the conventional negative electrode active materials.

Example 4

In this example, test cells were produced in the same manner as in Example 1 for evaluation of the electrode characteristics of the negative electrode active materials of various tellurides listed in Table 5. The evaluation was performed under the same conditions as applied in Example 1. All the test cells of Example 4 were found chargeable and dischargeable. Upon completion of cathode polarization at the 10th cycle, the test cells were disassembled and found to have no deposits of metallic lithium.

From this, it was indicated that the electrodes including the active materials in accordance with the present invention absorb therein lithium upon cathode polarization and desorb therefrom absorbed lithium upon anode polarization without growing dendrites of metallic lithium.

Next, for evaluation of the cycle life characteristics of the batteries applied with the negative electrodes of various tellurides in accordance with the present invention, cylindrical batteries as used in Example 1 were produced and evaluated under the same conditions as in Example 1. The results are summarized in Table 5.

Table 5

	Tellurides	Capacity (mAh/g)	Capacity maintenance rate (%)
5			
	Al_2MgTe_4	360	90
10	$MgSnTe_3$	550	85
	$MgSiTe_3$	400	80
	$MgPbTe_3$	600	90
15	$MgCdTe_2$	350	85
	$MgBi_2Te_6$	300	80
	$MgIn_2Te_4$	460	85
	$MgZnTe_2$	400	90
20	$MgGa_2Te_4$	390	85
	Mg_2GeTe_4	450	90
	Al_2CaTe_4	370	90
25	$CaSnTe_3$	570	90
	$CaSiTe_3$	400	85
	$CaPbTe_3$	600	90
	$CaCdTe_2$	390	85
30	$CaBi_2Te_6$	320	80
	$CaIn_2Te_4$	520	80
	$CaZnTe_2$	400	90
35	$CaGa_2Te_4$	390	85
	Ca_2GeTe_4	510	85
	Al_2SrTe_4	380	85
40	$SrSnTe_3$	630	95
	$SrSiTe_3$	450	90
	$SrPbTe_3$	600	85
	$SrCdTe_2$	400	85
45	$SrBi_2Te_6$	320	90
	$SrIn_2Te_4$	500	90
	$SrZnTe_2$	410	85
50	$SrGa_2Te_4$	410	90
	Sr_2GeTe_4	520	80

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Table 5-continued

	Tellurides	Capacity (mAh/g)	Capacity maintenance rate (%)
5			
10	Al_2BaTe_4	390	85
	BaSnTe_3	400	95
	BaSiTe_3	400	85
	BaPbTe_3	580	90
15	BaCdTe_2	390	80
	BaBi_2Te_6	410	80
	BaIn_2Te_4	530	85
20	BaZnTe_2	400	85
	BaGa_2Te_4	400	90
	Ba_2GeTe_4	500	90
	$\text{Ba}_{0.5}\text{Sr}_{0.5}\text{SnTe}_3$	600	95
25	$\text{Ba}_{0.7}\text{Sr}_{0.3}\text{SnTe}_3$	620	95
	$\text{Ba}_{0.9}\text{Sr}_{0.1}\text{SnTe}_3$	630	95
	$\text{Ba}_{0.5}\text{Ca}_{0.5}\text{SnTe}_3$	600	90
	$\text{Ba}_{0.5}\text{Mg}_{0.5}\text{SnTe}_3$	580	90
30	$\text{Ba}_{0.5}\text{Sr}_{0.5}\text{SiTe}_3$	500	90
	$\text{Ba}_{0.5}\text{Sr}_{0.5}\text{PbTe}_3$	620	90
	$\text{Al}_2\text{Na}_2\text{Te}_4$	420	90
35	Na_2SnTe_3	400	90
	Na_2SiTe_3	400	85
	Na_2PbTe_3	600	80
40	Na_2CdTe_2	400	85
	$\text{Na}_2\text{Bi}_2\text{Te}_6$	380	80
	$\text{Na}_2\text{In}_2\text{Te}_4$	550	85
	Na_2ZnTe_2	400	85
45	$\text{Na}_2\text{Ga}_2\text{Te}_4$	400	90
	Na_4GeTe_4	500	85
	$\text{Al}_2\text{K}_2\text{Te}_4$	430	90
50	K_2SnTe_3	450	90
	K_2SiTe_3	420	90

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Table 5-continued

	Tellurides	Capacity (mAh/g)	Capacity maintenance rate (%)
5			
10	K_2PbTe_3	580	85
	K_2CdTe_2	400	85
	$K_2Bi_2Te_6$	390	80
	$K_2In_2Te_4$	570	85
15	K_2ZnTe_2	400	85
	$K_2Ga_2Te_4$	400	90
	K_4GeSe_4	510	85
20	$SrAl_2SnTe_6$	550	90
	$SrAl_2SiTe_6$	400	85
	$SrAl_2PbTe_6$	600	80
	$SrAl_2CdTe_5$	350	90
25	$SrAlBiTe_5$	300	85
	$SrAlInTe_4$	460	80
	$SrAl_2ZnTe_5$	400	85
30	$SrAlGaTe_4$	390	90
	$SrAl_2GeTe_5$	450	85
	$BaSnAl_2Te_6$	360	90
	$BaSnSiTe_5$	400	85
35	$BaSnPbTe_5$	600	80
	$BaSnCdTe_4$	350	90
	$BaSnBi_2Te_8$	300	85
40	$BaSnIn_2Te_5$	460	80
	$BaSnZnTe_4$	400	85
	$BaSnGa_2Te_6$	390	90
	$BaSn_2GeTe_5$	450	85
45	$K_2SiAl_2Te_6$	360	90
	$K_2SiSnTe_5$	550	85
	$K_2SiPbTe_5$	600	80
	$K_2SiCdTe_4$	350	90
50	$K_2SiBi_2Te_8$	300	85

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Table 5-continued

	Tellurides	Capacity (mAh/g)	Capacity maintenance rate (%)
5			
	$K_2SiIn_2Te_6$	460	80
10	$K_2SiZnTe_4$	400	85
	$K_2SiGa_2Te_6$	390	90
	$K_2Si_2GeTe_5$	450	85
15	$MgPbAl_2Te_6$	360	90
	$MgPbSnTe_5$	550	85
	$MgPbSiTe_5$	400	80
	$MgPbCdTe_4$	350	90
20	$MgPbBi_2Te_8$	300	85
	$MgPbIn_2Te_6$	460	80
	$MgPbZnTe_4$	400	85
25	$MgPbGa_2Te_6$	390	90
	$MgPb_2GeTe_5$	450	85
	$CdAl_2Te_4$	360	90
	$CdSnTe_3$	550	85
30	$CdSiTe_3$	400	80
	$CdPbTe_3$	600	90
	$CdBiTe_4$	300	85
35	$CdIn_2Te_4$	460	80
	$CdZnTe_2$	400	85
	$CdGa_2Te_4$	390	90
	Cd_2GeTe_4	450	85
40	$SrBiAlTe_5$	360	90
	$SrBi_2SnTe_8$	550	85
	$SrBi_2SiTe_8$	400	80
45	$SrBi_2PbTe_8$	600	90
	$SrBi_2CdTe_7$	350	85
	$SrBiInTe_5$	460	80
50	$SrBi_2ZnTe_7$	400	85
	$SrBiGaTe_5$	390	90

Table 5-continued

	Tellurides	Capacity (mAh/g)	Capacity maintenance rate (%)
5			
10	BaInAlTe ₄	360	90
	BaIn ₂ SnTe ₆	550	85
	BaIn ₂ SiTe ₆	400	80
	BaIn ₂ PbTe ₆	600	90
15	BaIn ₂ CdTe ₅	350	85
	BaInBiTe ₅	300	80
	BaIn ₂ ZnTe ₅	400	85
20	BaInGaTe ₄	390	90
	BaIn ₂ GeTe ₅	450	85
	ZnAl ₂ Te ₄	360	90
	ZnSnTe ₄	550	85
25	ZnSiTe ₄	400	80
	ZnPbTe ₃	600	90
	ZnCdTe ₂	350	85
30	ZnBi ₂ Te ₆	300	80
	ZnIn ₂ Te ₄	460	85
	ZnGa ₂ Te ₄	390	90
	Zn ₂ GeTe ₄	450	85
35	MgGaAlTe ₄	360	90
	MgGa ₂ SnTe ₆	550	85
	MgGa ₂ SiTe ₈	400	80
40	MgGa ₂ PbTe ₆	600	90
	MgGa ₂ CdTe ₅	350	85
	MgGaBiTe ₅	300	80
	MgGaInTe ₄	460	85
45	MgGa ₂ ZnTe ₅	400	90
	MgGa ₂ GeTe ₅	450	85
	CaGeAl ₂ Te ₆	360	90
50	CaGeSnTe ₅	550	85

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Table 5-continued

Tellurides	Capacity (mAh/g)	Capacity maintenance rate (%)
CaGeSiTe ₅	400	80
CaGePbTe ₅	600	90
CaGeCdTe ₄	350	85
CaGeBi ₂ Te ₈	300	80
CaGeIn ₂ Te ₆	460	85
CaGeZnTe ₄	400	90
CaGeGa ₂ Te ₆	390	85

As shown in Table 5, the batteries using the various tellurides in accordance with the present invention as the negative electrode active materials are improved in the cycle life characteristics as compared with those using the conventional negative electrode active materials.

Example 5

In this example, various lithium composite compounds were prepared by intercalating a specified amount of lithium in MgSnO₃, SnSrBaO₃, CaSnS₃, SrSnSe₃ and BaSnTe₃ of the representative negative electrode active material of the present invention and evaluated for their electrode characteristics.

First, electrodes were produced using the above-listed active materials, which were then integrated in test cells in the same manner as in Example 1. Then, the lithium amount capable of intercalating in each of the electrodes was estimated by regulating the quantity of electricity consumed by cathode polarization and anode polarization. After tested, the cells were disassembled for quantitation of the lithium composite compounds by ICP spectrometry. This analysis confirmed a coincidence of the composition with the estimated composition in each composite compound.

Next, for evaluation of the cycle life characteristics of the batteries applied with the negative electrodes of the various lithium composite compounds of Example 5, cylindrical batteries as used in Example 1 were produced and evaluated under the same conditions as in Example 1. At that time, the intercalated lithium amount in the negative electrode active materials was adjusted by the amount of active material used.

After evaluation, the batteries were disassembled similarly to remove the negative electrode. The lithium composite compound thus harvested was quantitated by ICP spectrometry, which confirmed the composition of each compound.

The analytical results are shown in Table 6.

Table 6

	Lithium complex compositions	Capacity (mAh/g)	Capacity maintenance rate (%)
5			
	$\text{Li}_{0.1}\text{MgSnO}_3$	200	75
10	$\text{Li}_{0.5}\text{MgSnO}_3$	400	80
	LiMgSnO_3	550	80
	$\text{Li}_2\text{MgSnO}_3$	600	90
15	$\text{Li}_3\text{MgSnO}_3$	620	90
	$\text{Li}_4\text{MgSnO}_3$	650	95
	$\text{Li}_5\text{MgSnO}_3$	650	90
	$\text{Li}_6\text{MgSnO}_3$	670	95
20	$\text{Li}_7\text{MgSnO}_3$	680	95
	$\text{Li}_8\text{MgSnO}_3$	670	90
	$\text{Li}_9\text{MgSnO}_3$	640	90
25	$\text{Li}_{10}\text{MgSnO}_3$	580	85
	$\text{Li}_{11}\text{MgSnO}_3$	200	23
	$\text{Li}_{12}\text{MgSnO}_3$	125	15
	$\text{Li}_{0.1}\text{SnSbO}_3$	200	75
30	$\text{Li}_{0.5}\text{SnSbO}_3$	420	80
	LiSnSrBaO_3	550	85
	$\text{Li}_2\text{SnSrBaO}_3$	580	90
	$\text{Li}_3\text{SnSrBaO}_3$	600	90
35	$\text{Li}_4\text{SnSrBaO}_3$	630	90
	$\text{Li}_5\text{SnSrBaO}_3$	650	85
	$\text{Li}_6\text{SnSrBaO}_3$	670	85
40	$\text{Li}_7\text{SnSrBaO}_3$	680	85
	$\text{Li}_8\text{SnSrBaO}_3$	670	85
	$\text{Li}_9\text{SnSrBaO}_3$	640	85
	$\text{Li}_{10}\text{SnSrBaO}_3$	580	75
45	$\text{Li}_{11}\text{SnSrBaO}_3$	200	30
	$\text{Li}_{12}\text{SnSrBaO}_3$	125	10
	$\text{Li}_{0.1}\text{CaSnS}_3$	200	75
50	$\text{Li}_{0.5}\text{CaSnS}_3$	400	80

Table 6-continued

5	Lithium complex compositions	Capacity (mAh/g)	Capacity maintenance rate (%)
	LiCaSnS_3	500	80
10	$\text{Li}_2\text{CaSnS}_3$	580	90
	$\text{Li}_3\text{CaSnS}_3$	580	90
	$\text{Li}_4\text{CaSnS}_3$	590	95
15	$\text{Li}_5\text{CaSnS}_3$	600	90
	$\text{Li}_6\text{CaSnS}_3$	600	95
	$\text{Li}_7\text{CaSnS}_3$	640	95
	$\text{Li}_8\text{CaSnS}_3$	620	90
20	$\text{Li}_9\text{CaSnS}_3$	600	85
	$\text{Li}_{10}\text{CaSnS}_3$	550	85
	$\text{Li}_{11}\text{CaSnS}_3$	200	23
25	$\text{Li}_{12}\text{CaSnS}_3$	125	15
	$\text{Li}_{0.1}\text{SrSnSe}_3$	200	75
	$\text{Li}_{0.5}\text{SrSnSe}_3$	400	80
	LiSrSnSe_3	550	80
30	$\text{Li}_2\text{CaSnSe}_3$	600	90
	$\text{Li}_3\text{CaSnSe}_3$	620	90
	$\text{Li}_4\text{CaSnSe}_3$	630	90
35	$\text{Li}_5\text{CaSnSe}_3$	650	90
	$\text{Li}_6\text{CaSnSe}_3$	650	95
	$\text{Li}_7\text{CaSnSe}_3$	650	95
	$\text{Li}_8\text{CaSnSe}_3$	670	85
40	$\text{Li}_9\text{CaSnSe}_3$	640	80
	$\text{Li}_{10}\text{CaSnSe}_3$	580	85
	$\text{Li}_{11}\text{CaSnSe}_3$	190	32
45	$\text{Li}_{12}\text{CaSnSe}_3$	125	10
	$\text{Li}_{0.1}\text{BaSnTe}_3$	200	75
	$\text{Li}_{0.5}\text{BaSnTe}_3$	320	80
	LiBaSnTe_3	450	80
50	$\text{Li}_2\text{BaSnTe}_3$	600	90

Table 6-continued

5	Lithium complex compositions	Capacity (mAh/g)	Capacity maintenance rate (%)
10	$\text{Li}_3\text{BaSnTe}_3$	620	90
	$\text{Li}_4\text{BaSnTe}_3$	650	95
	$\text{Li}_5\text{BaSnTe}_3$	650	90
	$\text{Li}_6\text{BaSnTe}_3$	670	95
15	$\text{Li}_7\text{BaSnTe}_3$	690	95
	$\text{Li}_8\text{BaSnTe}_3$	670	90
	$\text{Li}_9\text{BaSnTe}_3$	640	90
20	$\text{Li}_{10}\text{BaSnTe}_3$	600	80
	$\text{Li}_{11}\text{BaSnTe}_3$	210	23
	$\text{Li}_{12}\text{BaSnTe}_3$	135	15
25			

30 The lithium composite compounds represented by the composition formula $\text{Li}_x\text{Z}_y\text{X}_y$ were found to manifest excellent electrode characteristics in a range of $1 \leq x < 10$. In other words, in that range, those compounds grow no metallic lithium dendrites and show good reversibility with high discharge capacity maintenance ratios.

35 When $10 \leq x$, poor cycle life characteristics were confirmed in the composite compounds. This may be because those compounds are prone to produce inactive lithium due to too much intercalation of lithium, resulting in poor cycle life characteristics. If the lithium amount is regulated to $0 < x < 1$, those compounds fail to produce a sufficient capacity for a battery upon operation of the battery due to small amounts of utilizable lithium.

In the foregoing examples, although oxides, sulfides, selenates and tellurides were used, identical results may be expected from the compounds comprising two or more elements selected from the group consisting of oxygen, sulfur, selenium and tellurium as well as the above-mentioned metals or semi-metals, for example, those oxides whose oxygen is replaced in part by sulfur or those sulfides whose sulfur is replaced in part by selenium.

40 In the foregoing examples, alkali metal or alkaline earth metal element were used as the group D element included in the oxides, sulfides, selenates and tellurides, but compounds whose elements are replaced in part by other elements selected from group D can also produce similar effects.

In the foregoing examples, cylindrical batteries were used, but the present invention is not limited to such battery configuration and can exert identical inventive effects when applied to coin-shaped, angular or flat secondary batteries.

45 The foregoing examples used $\text{LiMn}_{1.8}\text{Co}_{0.1}\text{O}_4$ as the positive electrode, but any other positive electrode active materials having reversible chargeability and dischargeability including LiMn_2O_4 , LiCoO_2 , LiNiO_2 and the like may be used to obtain similar effects.

50 As discussed above, according to the present invention, a highly reliable non-aqueous electrode secondary battery which is free of dendrite-induced short-circuiting and affords a high energy density can be obtained by an application of a negative electrode with a high capacity and an exceptional cycle life.

Claims

- 55 1. A non-aqueous electrolyte secondary battery comprising a chargeable and dischargeable positive electrode, a non-aqueous electrolyte and a chargeable and dischargeable negative electrode, said negative electrode comprising a compound represented by the formula



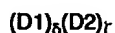
wherein Z represents at least two elements selected from the group consisting of metals and semi-metals at least one of which is selected from group D consisting of Na, K, Rb, Cs, Mg, Ca, Sr, Ba, Sc, Y, La, Ce, Ti, Zr, Hf, V, Nb, Ta, Cr, Mo, W, Mn, Fe, Co, Ni, Cu, Ag, Zn, Cd and Pd, and X represents at least one element selected from the group consisting of O, S, Se and Te and wherein $0 < \kappa + \gamma + \epsilon \leq 25$, $0 \leq \kappa < 10$, $0 < \epsilon < 10$ and $0 < \gamma \leq 8$.

2. The non-aqueous electrolyte secondary battery in accordance with claim 1, wherein Z comprises at least one element D selected from said group D and at least one element A selected from group A consisting of Si, Ge, Sn, Pb, Bi, P, B, Ga, In, Al, As and Sb and is represented by the formula



wherein $0 < \alpha$, $0 < \beta$ and $\alpha + \beta = \epsilon$.

3. The non-aqueous electrolyte secondary battery in accordance with claim 1, wherein Z comprises two elements D1 and D2 selected from said group D and is represented by the formula



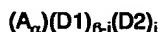
wherein $0 < \delta$, $0 < \zeta$ and $\delta + \zeta = \epsilon$.

4. The non-aqueous electrolyte secondary battery in accordance with claim 1, wherein Z comprises three elements D1, D2 and D3 selected from said group D and is represented by the formula



wherein $0 < \delta$, $0 < \zeta$, $0 < \eta$ and $\delta + \zeta + \eta = \epsilon$.

5. The non-aqueous electrolyte secondary battery in accordance with claim 2, wherein Z comprises one element A selected from said group A and two elements D1 and D2 selected from said group D and is represented by the formula



wherein $0 < i < \beta$.

6. The non-aqueous electrolyte secondary battery in accordance with claim 2, wherein Z comprises two elements A1 and A2 selected from said group A and one element D selected from said group D and is represented by the formula



wherein $0 < j < \alpha$.

7. The non-aqueous electrolyte secondary battery in accordance with claim 1, wherein said at least one element selected from said group D is an alkaline earth metal element.

8. The non-aqueous electrolyte secondary battery in accordance with claim 2, 5 or 6, wherein said metal selected from said group A is tin.

9. The non-aqueous electrolyte secondary battery in accordance with claim 8, wherein said at least one element selected from said group D is an alkaline earth metal element.

FIG. 1

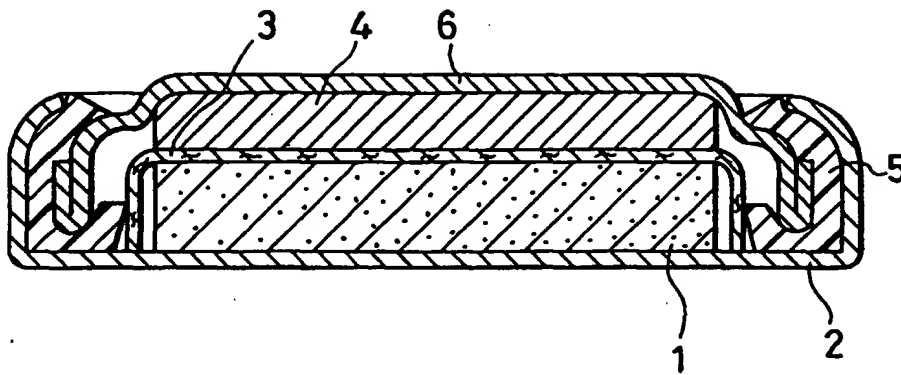


FIG. 2

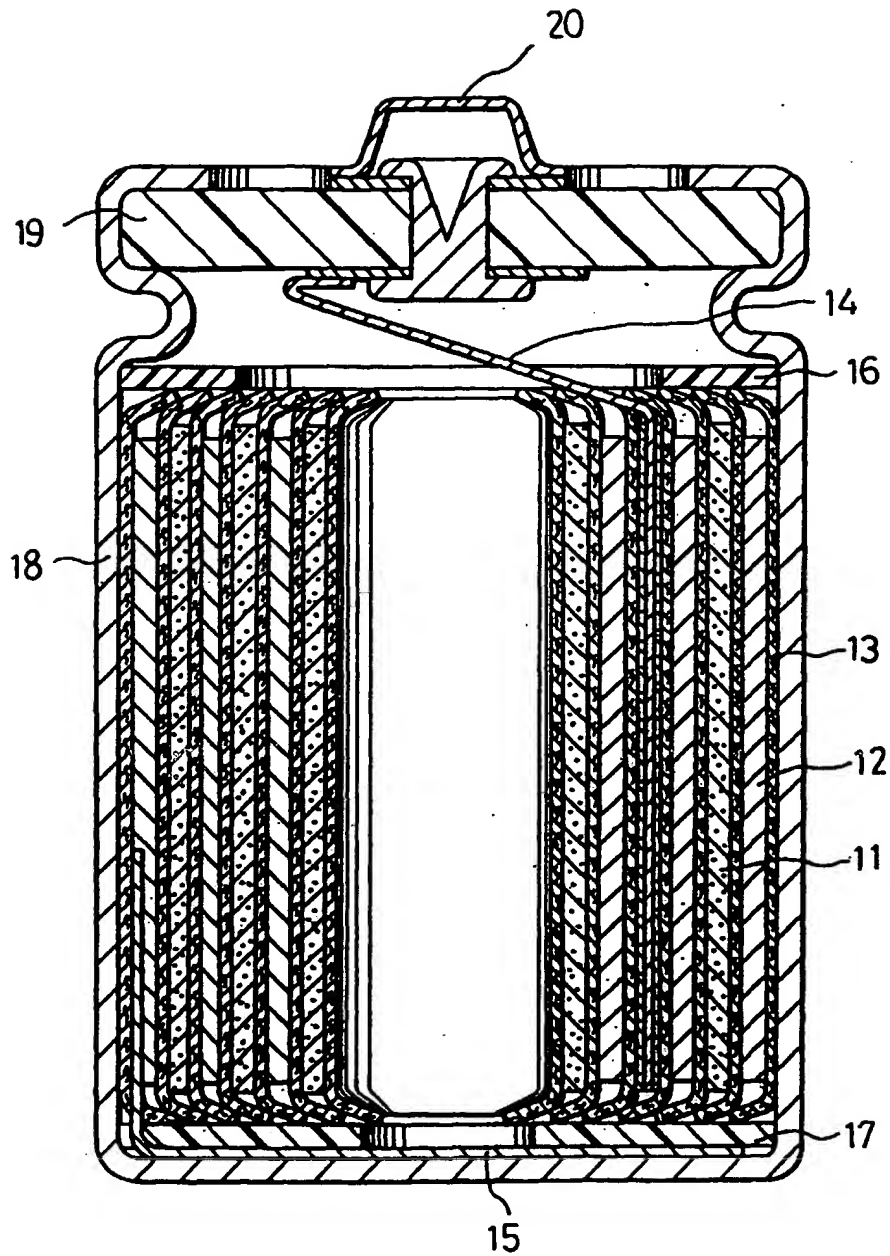
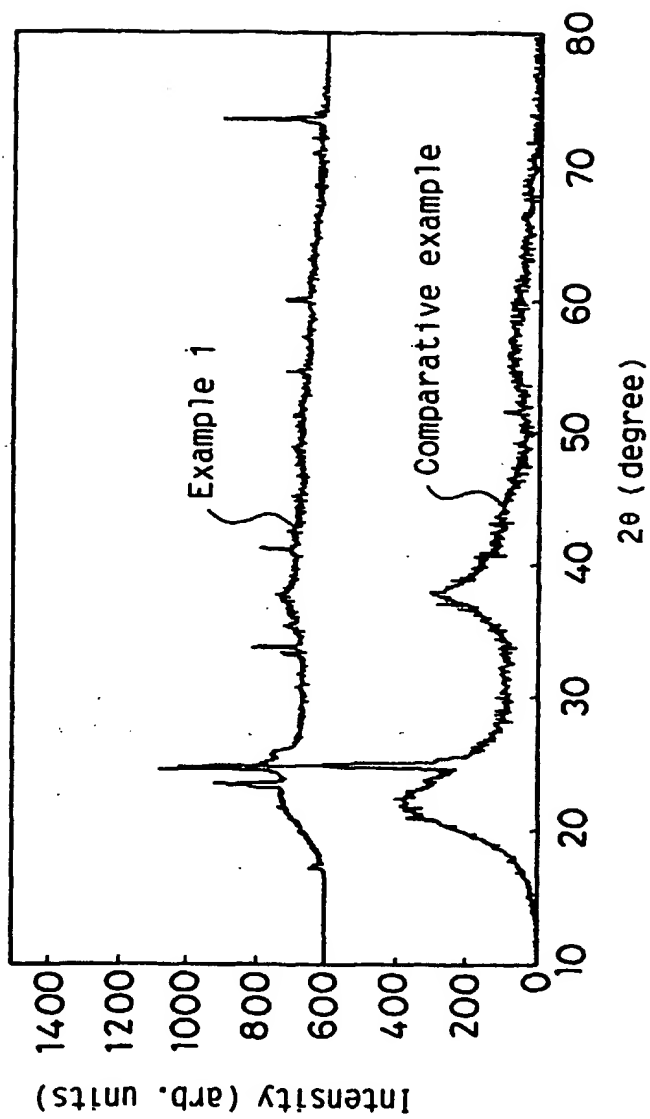


FIG. 3



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